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GB-1984-11

(12) UK Patent Application (19) GB (1) 2 140 626 A

(43) Application published 28 Nov 1984

(21) Application No 8410530

(22) Date of filing 25 Apr 1984

(30) Priority data

(31) 3314899 (32) 25 Apr 1983 (33) DE

(71) Applicant
Gerhard Mesenich,
Alte Bahnhofstr 58, 463 Bochum 7, Federal Republic of
Germany

(72) Inventor
Gerhard Mesenich

(74) Agent and/or address for service
G. F. Redfern & Co., Marlborough Lodge, 14
Farmcombe Road, Worthing, West Sussex, BN11 2BT

(51) INT CL³
H01F 7/16

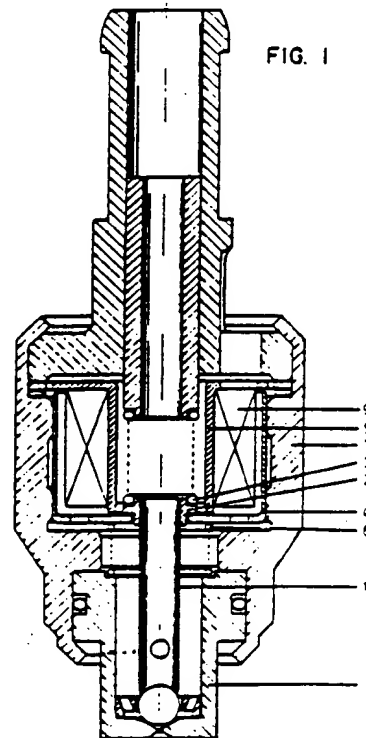
(52) Domestic classification
H1P 1C 1G 2D 2J
U1S 1901 1990 2241 H1P

(56) Documents cited
GB 1540324 WO 8300770

(58) Field of search
H1P

(54) Electromagnetic actuator incorporating anti-chatter device

(57) A supplementary mass 1, 2 is arranged in an electromagnetic system e.g. a valve, between armature 4 and reset spring 3 in such a way that, after reaching an end position, the armature is relieved of the spring force. Due to the relief, a high excess of magnetic force is available for braking the subsequent bounce movement. The mass and force conditions of the magnet system are matched so that the subsequent collision of armature 4 and supplementary mass 1, 2 occurs counter-directionally and the remaining kinetic energy of the armature is used up to a large extent by the counter-directional collision. The small bounce movement permits the use of spring systems with very high reset forces when the armature is pulled-in whereby the movement times of the armature are greatly shortened. As shown, in one arrangement the supplementary mass is the valve needle 1. In other arrangements the mass is a tube above the armature or between a reset spring and the armature.



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FIG. 1

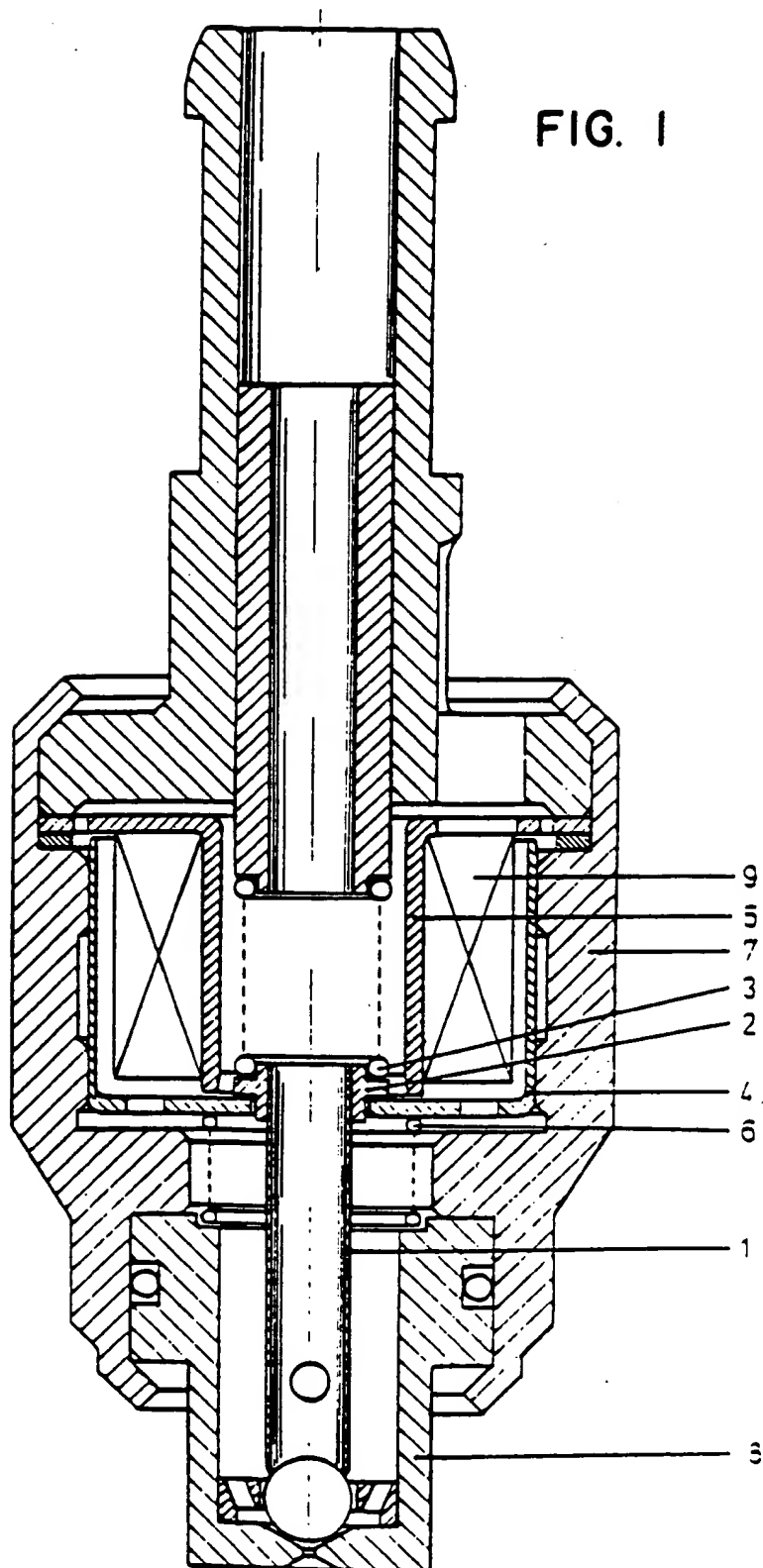


FIG. 4

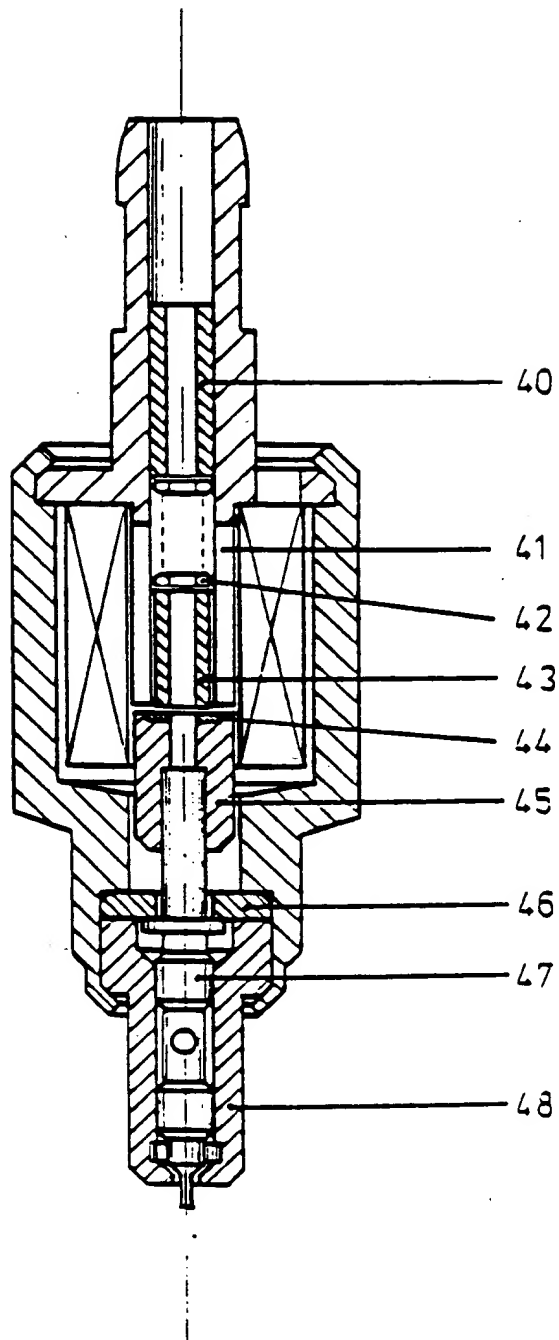


FIG. 5

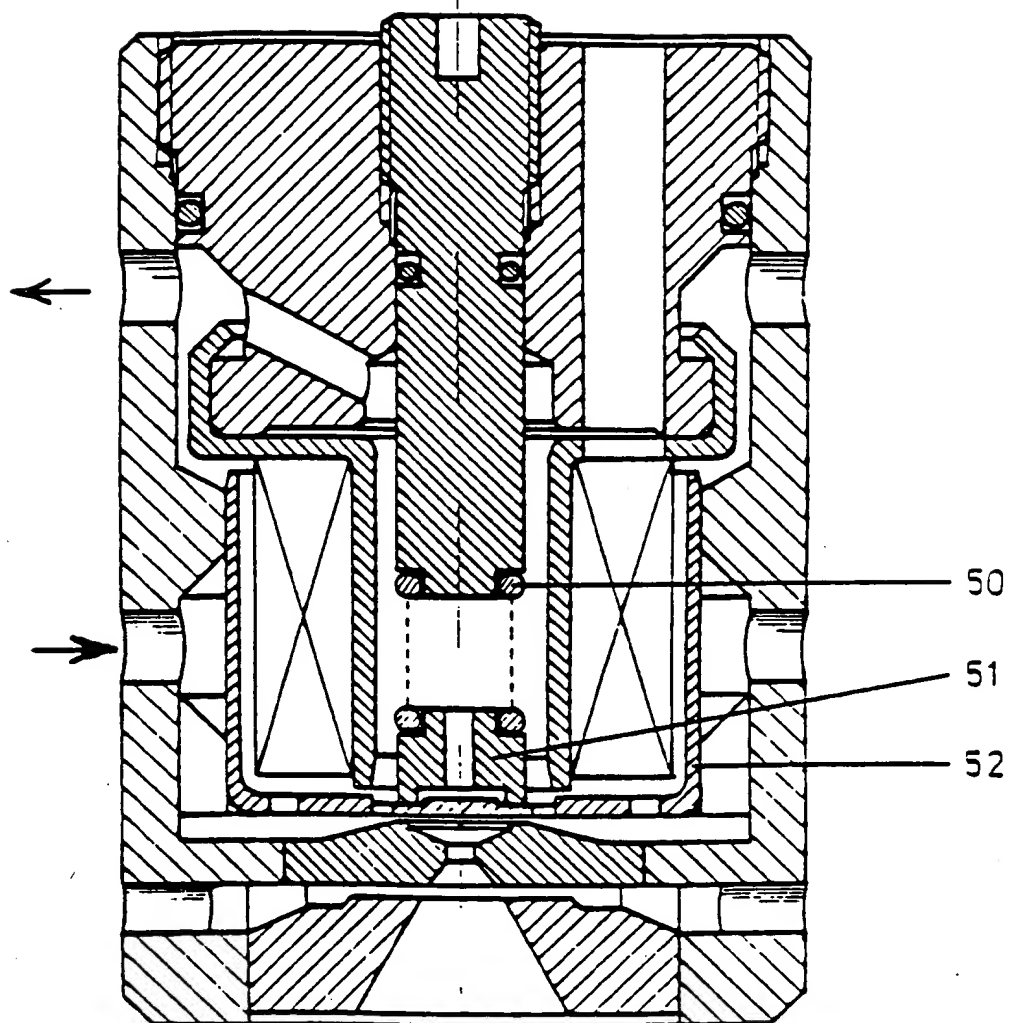


FIG. 6

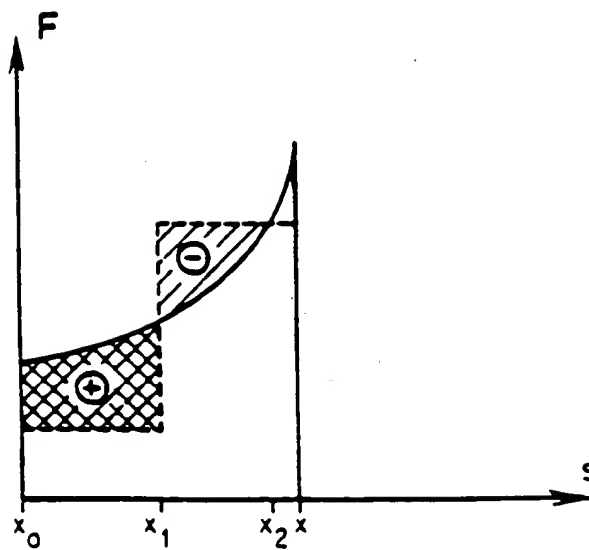


FIG. 7

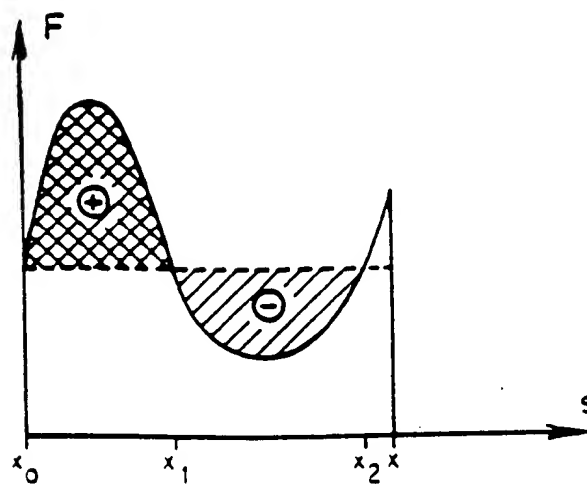


FIG. 12

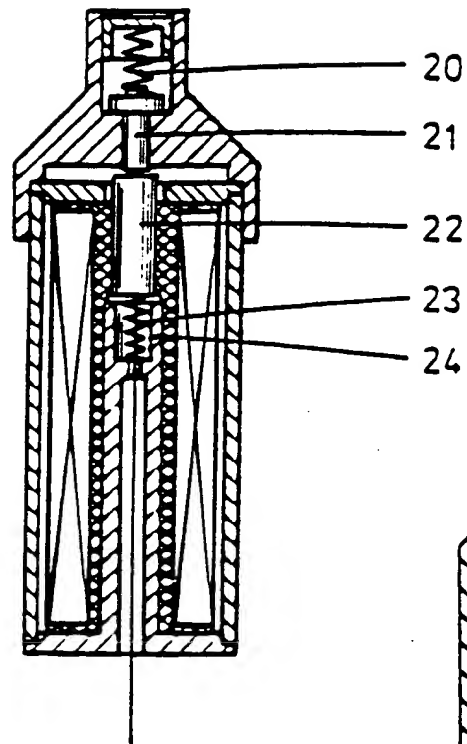


FIG. 8

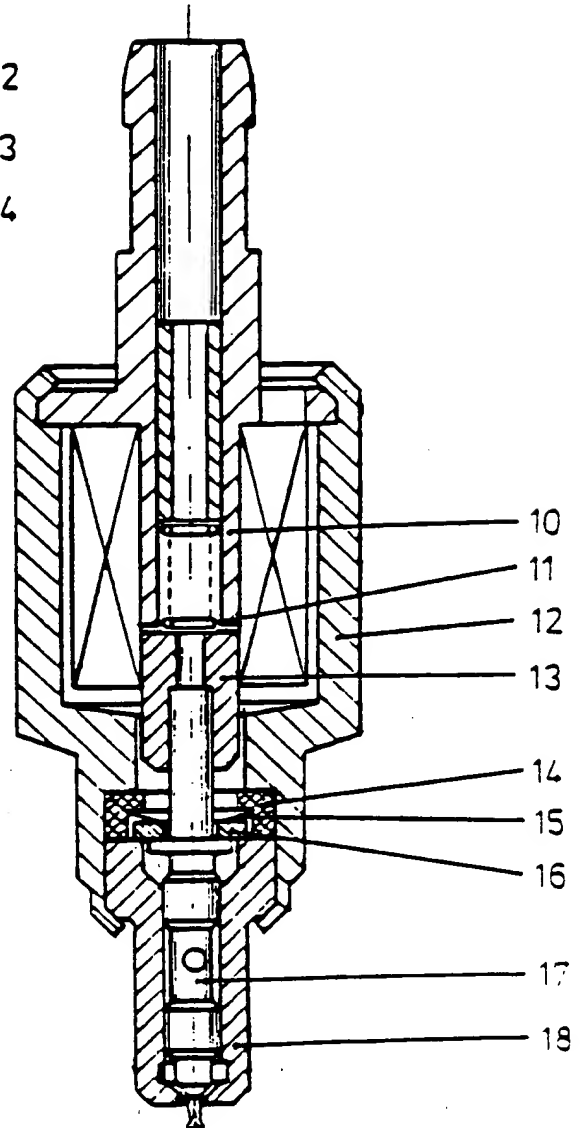


FIG. 9

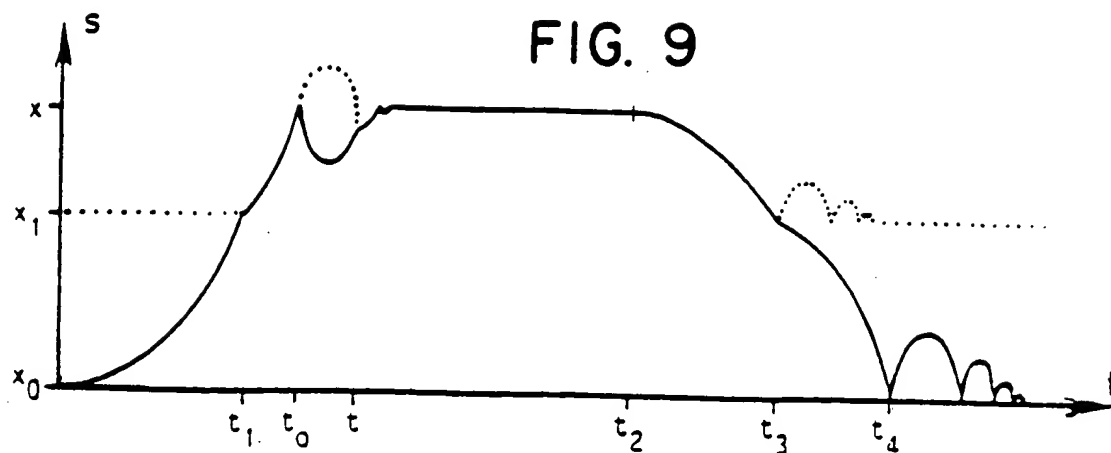


FIG. 10

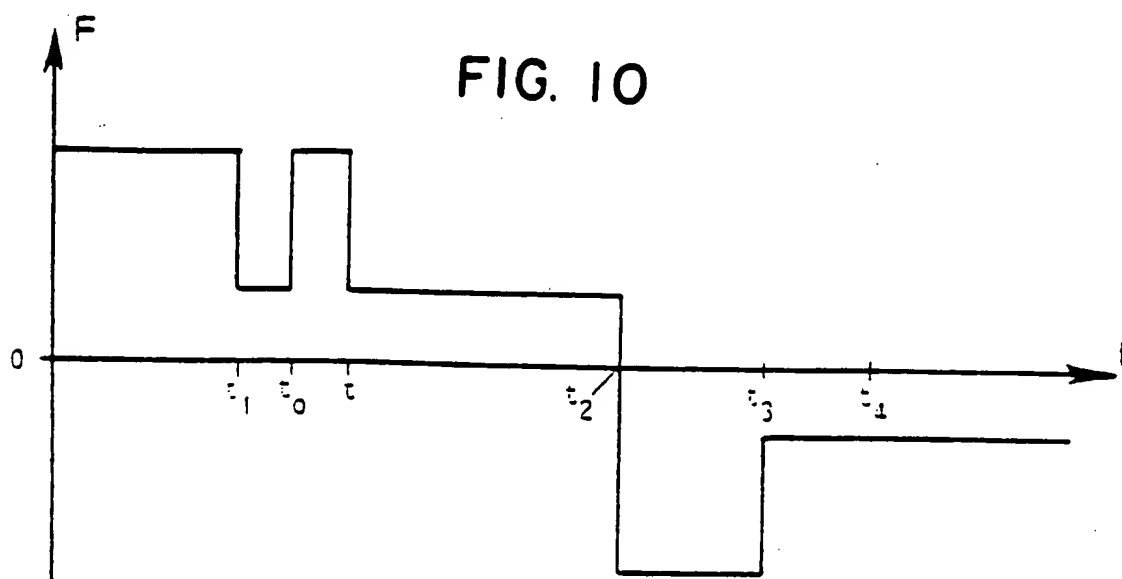


FIG. 11

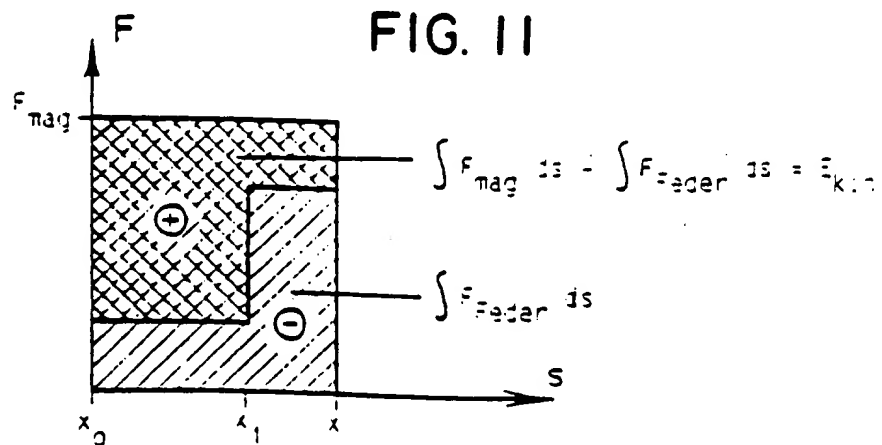
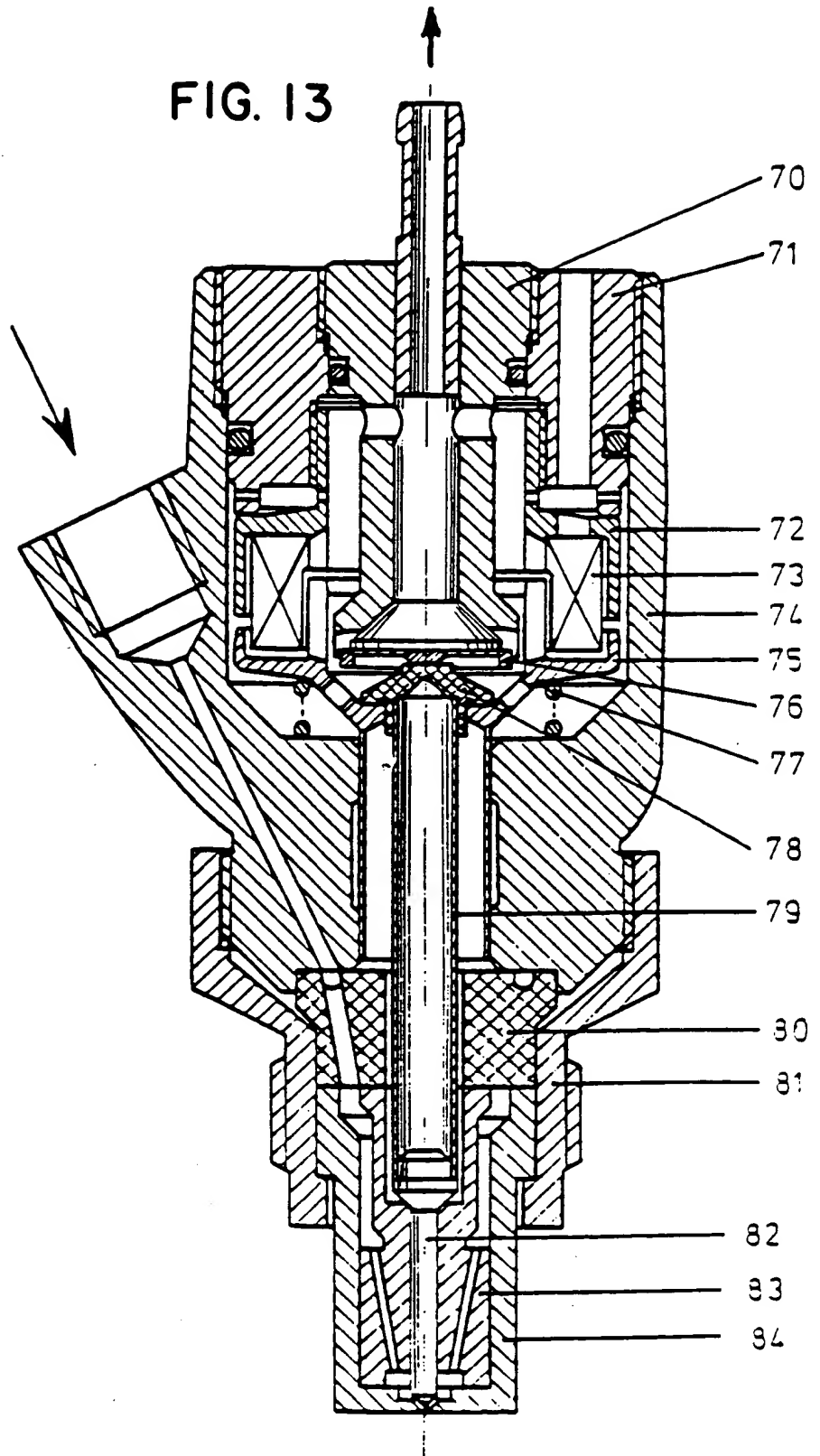


FIG. 13



SPECIFICATION

Spring Arrangement with Additional Mass for Improvement of the Dynamic Behavior of Electromagnetic Systems

5 Field of the Invention

This invention relates generally to electromagnetic motor means or systems and more particularly to such motor means or systems employed as actuating means as in high speed fuel injection valve assemblies, electromagnetic printers, rapid hydraulic valves and the like.

Background of the Invention

Common to all prior art electromagnetic motor means or systems is an electromagnetic circuit consisting of an exciting coil, armature and magnetic flux return. After the exciting current has been applied to the coil, the armature is moved into an end position counter to the force of one or more springs. To obtain a sufficiently short pull-in or pull-up process, the spring force must be only a fraction of the pull-in or pull-up force of the magnet system. Yet, toward the end of the pull-in process the excess force of the magnet is generally not sufficient to prevent rebound of the armature. The bounce is stronger as the excess of the magnetic force over the spring force is smaller.

During the bounce process it is not possible to disconnect the coil current without thereby impairing the reproducibility of the actuation process. If the coil current is disconnected before termination of the bounce process different movement conditions of the armature result, depending on whether at the time of disconnection the armature is moving counter to or in the reset direction.

As the coil current is being terminated, the reset movement is delayed by eddy currents in the magnetic circuit and by damping (attenuation) of the coil. The armature movement begins as soon as the spring force exceeds the induction force caused by eddy currents and damping and the remanent magnetic force.

To obtain a short reset delay, it is customary, in the prior art, to provide a residual air gap, which, however, increases the holding current requirement and hence the energy consumption of the electromagnet. Short reset delay times are achieved only with high spring forces, which, however, reduce the excess of the magnetic force and hence increase the chatter or bounce.

Accordingly, the invention as herein disclosed and described is primarily directed to the solution of the aforestated problems and other related and attendant problems of the prior art.

Summary of the Invention

According to one aspect of the invention, a spring arrangement with supplementary mass for improving the dynamic behavior of an electromagnetic system, comprises one or more supplementary masses disposed between the armature means and reset spring means, at least

one supplementary mass not forming a part of the mechanism to be actuated serves for the suspension of the reset spring means, the mass of the supplementary mass is substantially less than that of the armature means and can continue to move counter to the force of one or more of said reset spring means even after an end position of the armature has been reached so that after reaching such an end position of the armature means the armature means is relieved of reset spring means force by the supplementary mass continuing to move during a period of time which is considerable as compared with the bounce time of the armature means so that a high excess of force is available for braking the rebound movement of the armature means and thereby greatly shortening the bounce time of the armature means.

According to another aspect of the invention, a spring arrangement with supplementary mass for improving the dynamic behavior of an electromagnetic system, comprises at least one supplementary mass inserted between the armature means and one or more reset spring means, the mass of the supplementary mass is substantially less than that of the armature means and can continue to move counter to the force of one or more of said reset spring means even after an end position of the armature means has been reached, wherein said supplementary mass may be formed also by the mechanism to be actuated, wherein after an end position has been reached by the armature means the armature means is relieved of the force of at least one of said reset spring means by the supplementary mass continuing to move, and wherein the force and mass ratios of the system are adapted so that the movement energy remaining after impingement of the armature means is dissipated to a large extent in a second counter-directional collision of said armature means and said supplementary mass.

It is an object of the invention to accelerate the armature pull-in process by an adapted spring characteristic, to at least to a great extent eliminate armature chatter or bounce, and to shorten the time of the reset process by high reset forces. Consequently, by the then existing possibility of a reduced residual air gap, the energy requirement of the magnet and the required erasing power of the drive electronics is reduced and the pull-in process accelerated.

Other various general and specific objects, advantages and aspects of the invention will become apparent when reference is made to the following detailed description considered in conjunction with the accompanying drawings.

Brief Description of the Drawings

In the drawings, wherein for purposes of clarity certain details and/or elements may be omitted from one or more views:

Figure 1 is an axial cross-sectional view of an electromagnetic system, employing teachings of the invention, as may be employed, for example,

the kinetic energy of the two bodies is dissipated to a large extent. Thereafter the armature and needle valve move to the end position at a much reduced speed under the influence of the magnetic force. For comparison the movement which would result if the armature and needle valve were firmly connected, as in conventional systems, is also shown (in dash line).

As should be apparent, in the conventional prior art systems the much stronger chatter results in an undesired increase of the reproducibly injectable fuel quantity.

Figure 3 shows the spring force and magnetic force acting on the armature. At the beginning of the movement, the armature is accelerated by the excess of magnetic force over the spring forces. At time, t_0 , the armature is relieved of the resetting spring force, so that the total magnetic force is available for braking the chatter. After the armature and needle valve have collided in opposite directions at time, t , the armature is pulled into the end position at a greatly reduced speed.

In the injection valve of the invention as shown in Figure 1, the supplementary mass was formed by the needle valve. This resulted in the advantage that after the closing of the valve the chatter process could be shortened by a high excess of force of the reset spring. However, in injection valves for injection of fuel into the induction passage of internal combustion engines the accuracy of fuel metering is influenced only slightly by the chatter process after the closing of the valve because the chatter process, after the closing of the valve, always occurs in the same reproducible manner. The known prior art injection valve models, in which the armature is directly connected with the valve member or in which the armature itself forms the valve member can therefore be improved in a particularly simple manner by disposing the supplementary mass between armature and reset spring.

Figure 4 shows such an arrangement of the supplementary mass of the invention embodied as within an otherwise known prior art injection valve assembly. The armature 45 is firmly connected with the needle valve 47. The needle valve is guided with little radial play by the nozzle body 48 and the stroke of the needle valve is limited by the stop plate 45. The armature is reset by the reset spring 42. The movable tubular supplementary mass 43 of non-magnetizable material is located between the reset spring and armature. After the needle valve strikes against the stop plate 45 the supplementary mass continues its path and thereby relieves the armature of the force of the reset spring. The movement conditions are matched to one another in the manner already described. In addition, a plate 44 of damping plastic is embedded in the armature. By the provision of plate 44 an additional dissipation upon collision of armature and supplementary mass in opposite directions is achieved. Further, as the valve closes, there is

created by the plate 44 a force peak which shortens the subsequent chatter process. However, the effect of the plate on the movement conditions is generally not very great, so that in the interest of easy manufacture the plate may be dispensed with.

Figure 5 shows, as a further example of the invention, a fuel injection valve where the armature itself serves as the valve member. Here, the supplementary mass 51 is disposed between armature 52 and reset spring 50. A similar arrangement can be adopted also for injection valves which have, as armature and valve member, a ball of magnetizable material and a reset spring. To this end an annular supplementary mass is disposed between the ball and the reset spring. If appropriately shaped, the annular supplementary mass may alternatively consist of magnetizable material, to reduce the leakage losses and to increase the working air gap induction.

By matching of the mass and force ratios as thus far disclosed and described, the chatter is drastically shortened and thereby the reproducibly injectable fuel quantity is substantially reduced. A definite improvement of the chatter can, however, be also achieved, without matching of the movement conditions, if during a period which is long in comparison to the chatter time the armature is relieved of the reset spring force by the continued movement of the supplementary mass so that a high excess of magnetic force is available for braking the rebound movement of the armature.

With the spring arrangement and supplementary mass, as thus far disclosed, the speed of the pull-in and reset movement is not yet influenced. A substantial shortening of both the pull-in and the reset movement with simultaneous reduction of the chatter is achieved by the combination of a multi-mass system with a specific spring arrangement.

To better explain the mechanism of action, consider, generally, first the motion as being a function of the force. That is, the kinetic energy and hence the impingement speed of a body moving without friction depends exclusively on the work supplied. The work supplied is the integral of the force gradient versus path. At equal supplied work the type of force gradient is of no importance for the kinetic energy. However, for the velocity gradient of the movement it is by no means immaterial in what form of force gradient the drive work is supplied. Much acceleration work at the beginning of the movement leads to a high velocity level which is maintained during the entire movement and hence leads to short movement times. At high release (application) of work toward the end of the movement, on the contrary, increases only the impact velocity and hence the chatter without substantially shortening the movement time. With a movement where the total acceleration work is released at the beginning, the movement time is cut in half as

mass ratio between armature and supplementary mass, after appropriate selection of the spring force characteristic at a given magnetic force characteristic, depends almost exclusively on the energy loss upon collision of the separate parts. Depending on the rest of the dimensions, in electromagnetic injection valves, according to the invention, the supplementary mass should usually be about 5—20% of the armature mass.

In the prior art literature it is occasionally affirmed that the magnetic force must always exceed the external static forces acting on the armature in order not to cause the movement to cease. This is not correct, as this approach does not take into account the kinetic energy of the armature. In the interest of a soft, low-bounce movement it may even be favorable if the reset spring force exceeds the magnetic force on a portion of the path. The only condition for a smooth movement is that the kinetic energy of the moving parts before the intersection of the spring characteristic with the magnetic force characteristic is higher than the work integral of the spring force exceeding the magnetic force. By the excess spring force the kinetic energy of the moving parts is reduced in the desired manner toward the end of the movement process. However, at the instant of armature impingement here, too, the magnetic force must exceed the spring force in order to suppress the always existing chatter and to cause the movement to cease.

To illustrate this, Figures 6 and 7 show two characteristics where the magnetic force characteristic intersects the spring characteristic to improve the dynamic behavior. Figure 6 shows the typical magnetic force characteristic of a magnet system without influence on the characteristic, which is combined with a spring system whose characteristic has a sudden change. The magnetic force characteristic is shown as a solid line while the spring force characteristic is shown as a broken line. Up to point, x_1 , the magnetic force exceeds the spring force, so that the armature is accelerated. At point, x_1 , the kinetic energy of the armature corresponds to the integral of the cross-hatched area, which is marked by a plus sign. Upon continued movement the armature traverses a zone in which the spring force exceeds the magnetic force, so that the speed decreases again. The loss of kinetic energy corresponds to the integral of the hatched area. The condition for complete passage through the zone, in which the spring force exceeds the magnetic force, is merely that before entrance into the zone the kinetic energy of the armature is greater than the work integral of the static forces exceeding the magnetic force. In the graph, therefore, the cross-hatched area must be larger than the hatched area. To cause the movement to cease toward the end of the pull-in process it is further necessary, of course, that toward the end of the pull-in process the magnetic force exceeds the spring

force and the static forces. By appropriate matching of the path and force ratios, extremely soft, low-bounce and rapid armature movements can be obtained, in particular in combination with the previously described supplementary mass system of the invention.

Figure 7 shows the same relationships for a system with influence on the magnetic force characteristic. It illustrates that in special cases a strong influence on the dynamics is possible by intersection of the spring and magnetic force characteristics even if the spring force gradient is constant.

The technical realization of the foregoing elucidations are hereinafter more fully described with reference to further embodiments employing teachings of the invention.

Figure 8 shows a fuel injection valve for internal combustion engines which with respect to the geometry of the magnetic circuit generally corresponds to the conventional prior art designs. However, unlike the conventional prior art designs, the valve assembly of Figure 8 has two reset springs; that is, the helical spring 11 and the cup spring 15. The movable supplementary mass 16 is under the cup spring 15. The supplementary mass 16 rests on the valve body 18 so that, with the valve closed, a certain clearance remains between the strike plate of the needle valve 17 and the supplementary mass 16.

Upon application of the energizing current the armature 13, and the needle valve 17 firmly connected with the armature, are pulled-in counter to the force of the helical spring 11. After a part of the armature path has been travelled, the strike plate of the needle valve 17 impinges on the supplementary mass 16, whereby the spring force of the helical spring 11 is added to the spring force of the cup spring 15. Toward the end of the pull-in movement the armature 13 strikes against the magnet pole 10 and bounces back. The supplementary mass 16, however, can continue its movement, counter to the force of the cup spring 15, thereby relieving the armature and making available a high excess of magnetic force for the braking of the bounce movement.

Upon termination of the coil energizing current, the armature is reset by the joint force of the two springs. By the improved dynamics the reproducibly injectable fuel quantity is reduced to a fraction of the value of the usual prior art designs, whereby the metering accuracy is substantially improved especially in the critical idling range.

With the valve assembly illustrated in Figure 8 it has been possible to achieve the following improvements of the dynamics as compared with the usual prior art design, with almost constant spring forces gradient under equal electric drive conditions and at equal initial spring force. Because of the reduced residual air gap, with the valve assembly of Figure 8, the same pull-in times were obtained despite the much greater spring forces and the following bounce time was shortened to about 30% of the value of the

shoulder of the pressure piece 78. The pressure piece is mounted for axial movement in the armature with little radial clearance. The needle valve 82 is connected with the pressure piece via a connecting tube 79. The pressure piece, connecting tube and needle valve are acted upon by the diaphragm spring 76. The diaphragm spring acting as a reset spring has a steep spring force characteristic, so that toward the end of the pull-in process the reset force acting on the armature is barely below the saturation induction force of the magnet system. This results in a very good adaption of the magnetic force characteristic to the hydraulic force requirement of the needle valve and in a high excess of force at the beginning of the pull-in movement and reset movement.

After connection of the exciting current, the armature starts to move counter to the force of the reset spring. During the pull-in movement, a pressure compensation takes place under the needle valve, bringing about an additional strong compressive force on the needle valve in opening direction. The increasing compressive force onto the valve needle is overcompensated by the increasing force of the reset spring, so that at the beginning of the pull-in movement a high excess of magnetic force is available for acceleration, which toward the end of the pull-in movement disappears almost completely. After reaching the end position, the armature is relieved of the force of the reset spring, as has been shown before, so that the armature bounce quickly ceases. After termination of the coil energizing current, the full force of the reset spring 76 is again available, so that the armature moves back almost without delay with high acceleration. After the valve has closed, the connection between armature and needle valve breaks. By the reset spring force, which is high in relation to the needle valve mass, the subsequent bounce of the needle valve is effectively suppressed, thus preventing continued spraying. Thereafter the armature 75 is brought to a standstill by hydraulic damping forces and is made to abut on the shoulder of the pressure piece 78 by the weak force of the helical spring 77 at low speed, hydraulically damped.

Due to the spring characteristic well adapted to the dynamic and static requirements, the dimensions of the magnetic circuit can be greatly reduced. In fact, it is only through the high reset spring force that it is possible in the present application to obtain an acceptable reset delay at a small residual air gap.

To compensate differences between lots, calibration of the dynamic and hydraulic behavior by two adjusting screws has been provided. The spring force adjusting screw 70 changes the initial tension of the diaphragm spring while the support screw 71 changes the stroke of the armature and of the valve needle.

Through bores in the valve housing 74 and in the intermediate piece 80, the fuel, being under a pressure as constant as possible, is conducted to the seat of the needle valve 82. A small amount of

fuel leakage gets through the gap between needle valve and needle valve guide 83 into the valve housing and is then returned to the fuel tank at low pressure. The moving parts of the injection valve are lubricated by the backflowing fuel.

Production of the valve needle guide bore with small diameter at high precision is complicated. The valve can be simplified by making the housing pressure-proof and conducting the fuel under full system pressure directly into the housing, so that when the valve is open, the valve needle is relieved almost completely of unilaterally acting hydraulic forces. The diameter of the valve needle can then be increased without this leading to increased hydraulic interfering forces.

Another appropriate design is obtained by providing an injection valve with pressure-relieved armature space according to the embodiment of Figure 13 with a valve needle of large diameter, the then occurring additional hydraulic forces being compensated by an additional helical spring. The helical spring is arranged above the diaphragm spring in such a way that the almost constant force of the helical spring is added to that of the diaphragm spring.

The diaphragm spring 76 is reinforced in the center and on the outside. By the reinforcements, located at the points of greatest mechanical stress, the load capacity of the diaphragm spring is substantially increased. The spring constant of the diaphragm spring is dependent in greatest degree on the diaphragm thickness. The diaphragm spring is flat on one side, to adjust the spring constant by grinding the flat area down to equalize differences between lots. The spring constant depends also on the clamping conditions, however, so that its adjustment can be achieved also by cutting away or otherwise reducing the thickness of the reinforcements of the diaphragm spring.

It should now be evident that also in the case of injection valves which operate at low fuel pressures the dynamics can be improved by using reset springs with a steep spring characteristic. For injection valves where the armature and valve member are rigidly connected together an especially appropriate design results if the supplementary mass is firmly connected with a diaphragm spring and is made in one piece. Such a design can be employed, for example, for the injection valve according to Figure 8, in that the spacer ring 14, the cup spring 15 and the supplementary mass 16 are replaced by a diaphragm spring with a central bore and a central tubular reinforcement of the weight of the supplementary mass. The spacer ring 14 is replaced by the outer reinforcement of the diaphragm spring. The helical spring 11 can then be dispensed with.

In injection valves which have, as armature and valve member, a flat plate, the diaphragm spring with supplementary mass can be placed around the armature like a collar. Another appropriate design results if the diaphragm spring acts on the armature of the magnet system via a central

changing reset spring force characteristic is obtained by parallel connection or series connection of two springs and by stroke limitation of one of the two springs.

- 5 16. Spring arrangement with supplementary mass according to claim 14 wherein before and after the jump the spring characteristic is horizontal to the extent possible or drops off in the direction of the pull-in movement.
- 10 17. Spring arrangement with supplementary mass according to one of claim 14, wherein path up to the spring force jump is 40—90% of the total armature stroke.
- 15 18. Spring arrangement with supplementary mass according to claim 2 wherein the reset spring force characteristic is very steep so that toward the end of the pull-in process a greatly increased reset force is available which preferably lies just below the saturation induction force of
- 20 the magnet system, and at the beginning of the pull-in movement the reset force is preferably less than one half the saturation induction force.
- 25 19. Spring arrangement with supplementary mass according to claim 18 wherein a diaphragm spring is used to produce the steep spring force characteristic in magnet systems with very small armature stroke.
- 20. Spring arrangement with supplementary

- 30 mass according to claim 19 wherein the diaphragm spring is reinforced at the outer edge and/or in the center.

- 21. Spring arrangement with supplementary mass according to claim 20 wherein the central reinforcement of the diaphragm spring is preferably tubular and large enough for the central reinforcement to serve as supplementary mass.

- 22. Spring arrangement with supplementary mass according to claim 2 wherein the magnetic force characteristic intersects the spring force characteristic so that the armature speed is reduced after the intersection of the characteristics.

- 23. Spring arrangement with supplementary mass according to claim 21 wherein the residual air gap is greatly reduced or eliminated altogether.

- 24. Spring arrangement with supplementary mass according to claim 2 wherein in order to compensate differences between lots the dynamic behavior of the magnet system is calibrated by adjusting the initial tension or one or more springs of the system and/or by adjusting the armature stroke and/or the path to where the reset spring force jump is reached and/or by selecting springs with different spring constants.